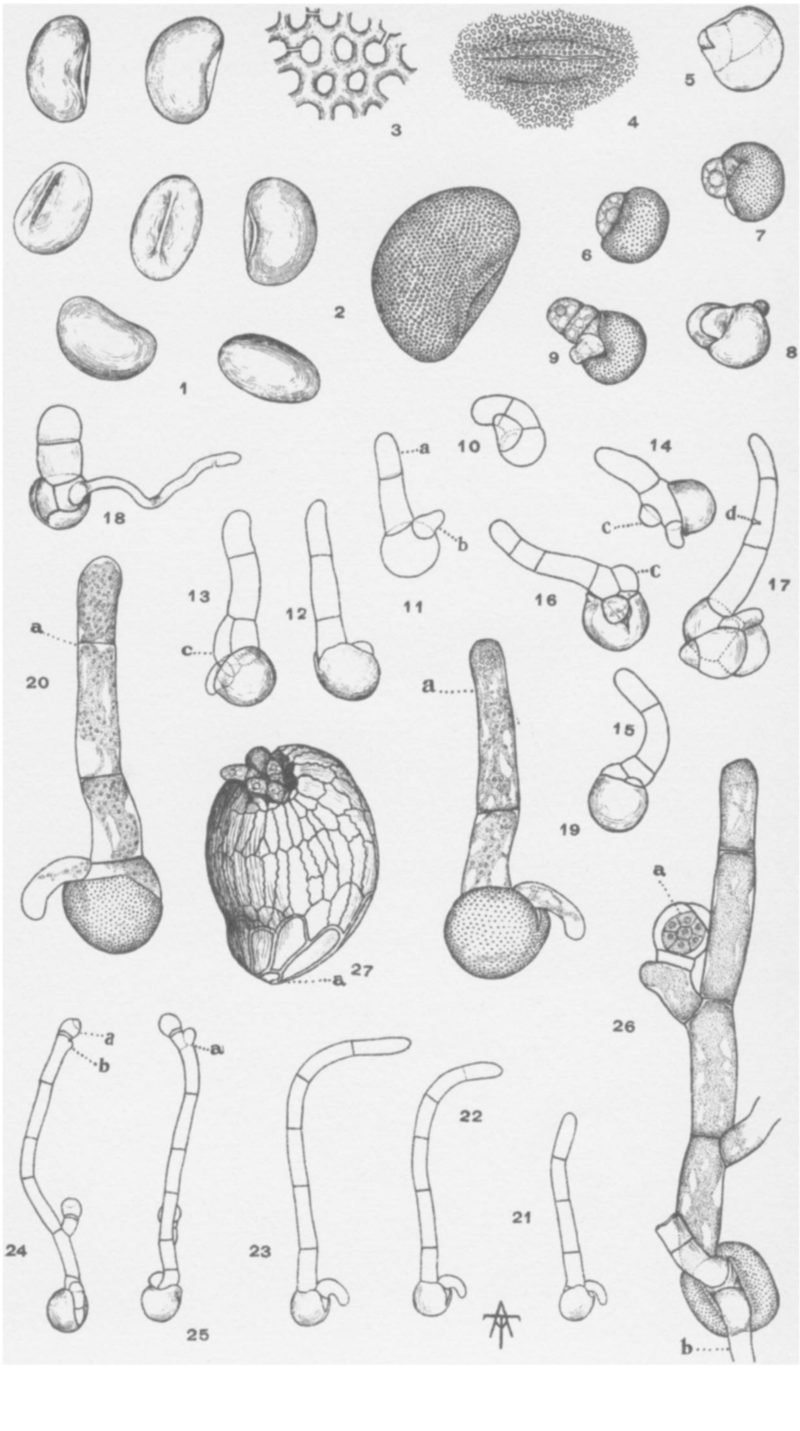

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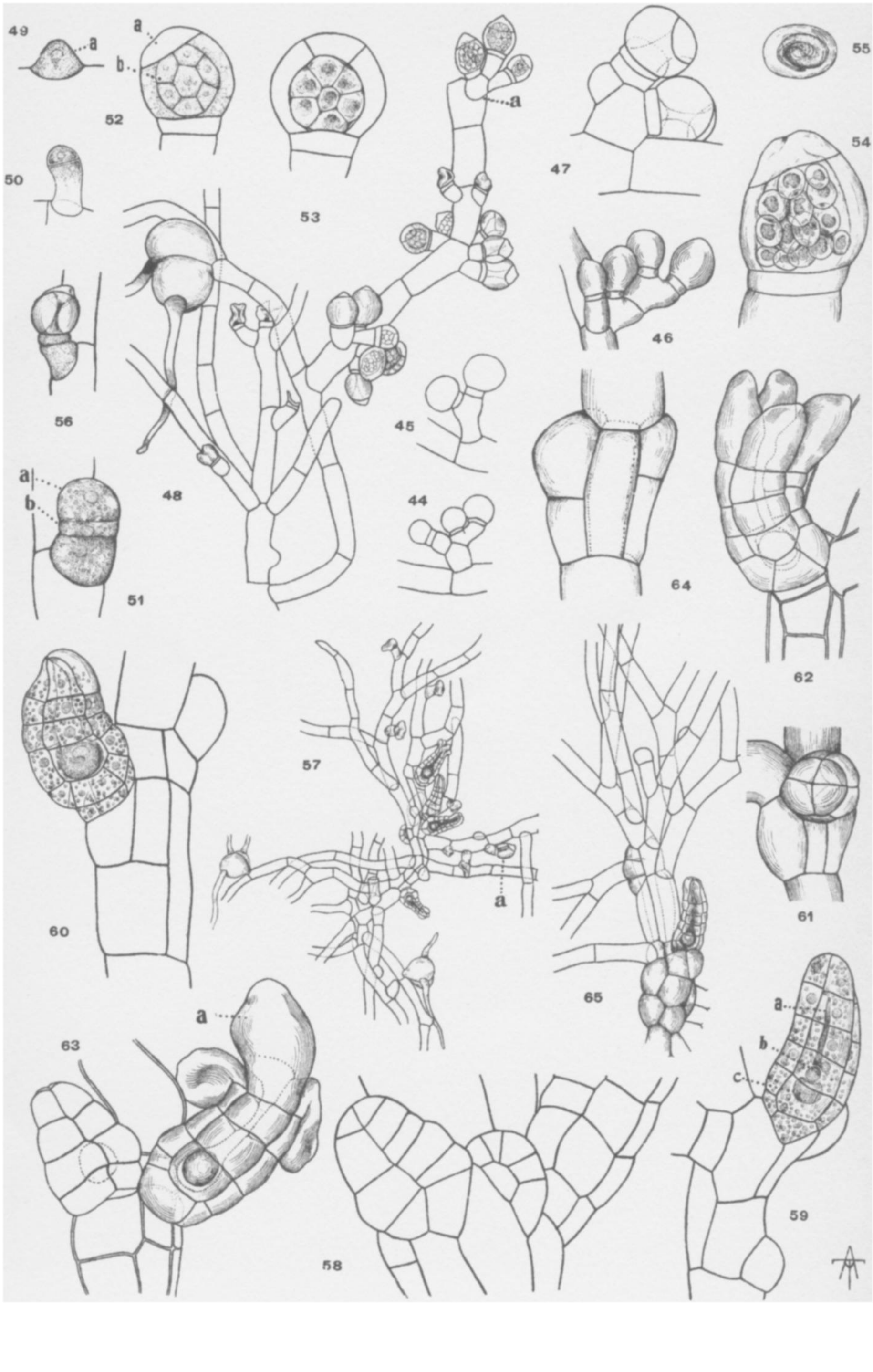

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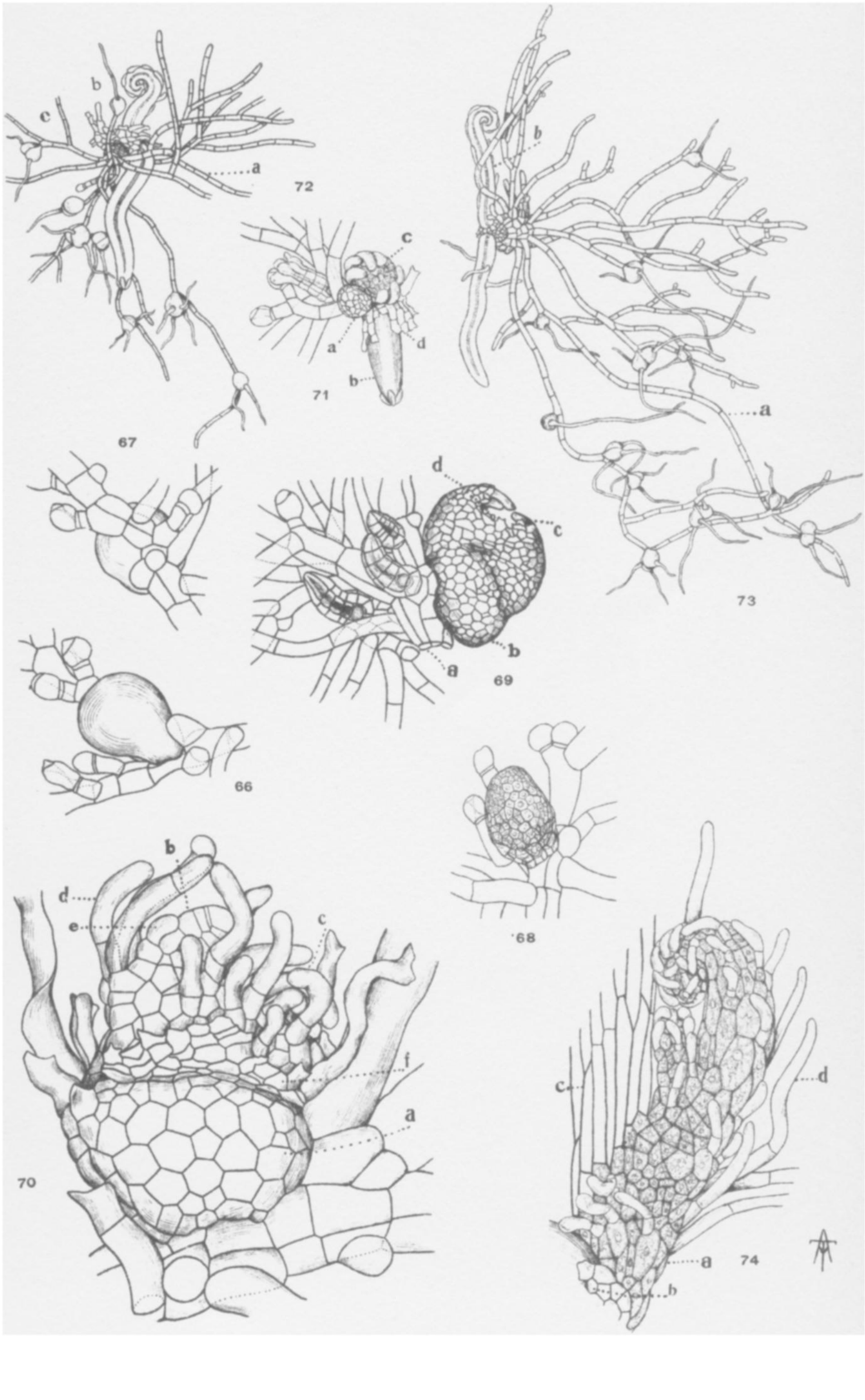
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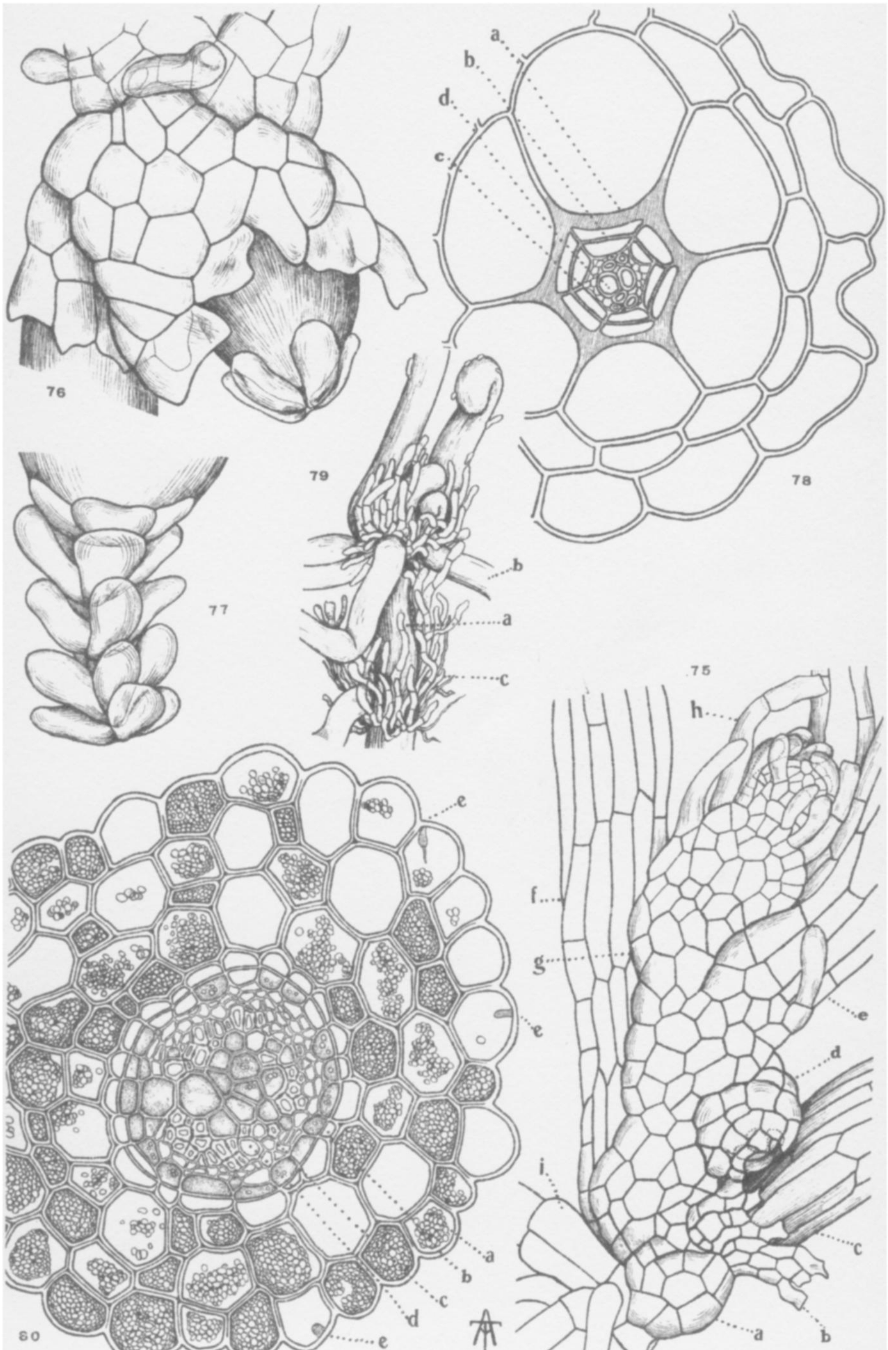
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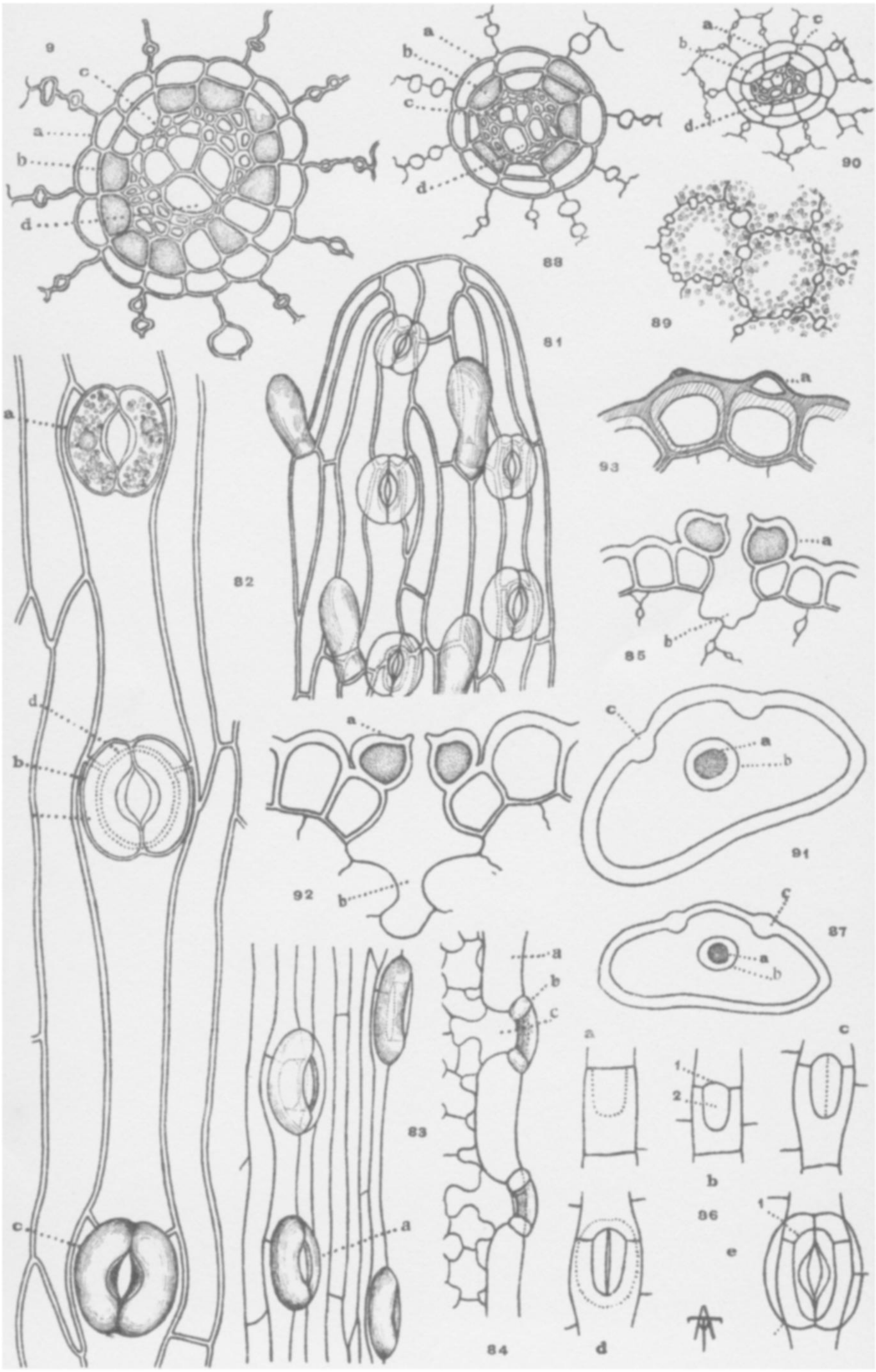
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Life History of Schizaea pusilla

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(WITH PLATES 1-6)

The material on which these studies were based was collected at Forked River, New Jersey, on the third of July, 1900. The plants were abundant, but only half grown, the sporophylls being only five centimeters high. They were found around the base of small white cedars (*Chamaecyparis thyoides*) kept moist by hummocks of *Sphagnum*, and surrounded by *Lycopodium Carolinianum*, *Juncus pelocarpus*, *Drosera rotundifolia* and *Utricularia cleistogama*. Young plants were found, ranging from two to ten millimeters in height, growing in depressions of moist sandy loam, or even perched upon the roots of sedges and *Sisyrinchium Atlanticum*. Several sods were taken with the plants in various stages, and a large number of young plants were collected and preserved in alcohol. With a magnification of fifteen diameters, it was discovered at the time of collection that they originated from a filamentous protonema, consisting of a tangled mass of dark green filaments, spreading around the base of the young circinate leaf, and that these filaments were persistent, even after some of the leaves were 10–15 mm. high. Entangled with the filaments, in such a manner as to render it necessary to clean them with a camel's-hair brush, there were three species of hepatics (*Odontoschisma sphagni* (Dicks.) Dumort; *Lophozia inflata* (Huds.) M. A. Howe; and *Cephalozia catenulata* (Hübn.) Spruce; also a slender fresh-water alga, *Rhizoclonium hieroglyphicum* (Ag.) Kütz.

[Issued 31 January.]

A complete or correct description of *S. pusilla* cannot be found in any manual or monograph. In several the spores are said to be smooth, and the glandular hairs borne by the leaves are not mentioned, though they are known on other species of this genus.

The gametophyte is composed of numerous, erect, branching, dark green protonemal filaments; monoicous, bearing from 5–12 archegonia, usually on a slightly thickened and expanded series of cells in the nature of an archegoniophore (?) or directly on the filaments; antheridia more numerous, often on separate branches and nearer the extremities of the filaments; radicles seldom borne on the filament but produced from specially modified, large spherical cells, apparently in symbiotic relation with a fungus. Sporophyte perennial, from a short erect or horizontal rootstock, 5–10 mm. long, sterile leaf 2–5 cm. long by 0.5 mm. broad, circinate, bearing small club-shaped hairs, nearly 1 mm. long, occurring in three longitudinal rows on the dorsal surface, alternating with two rows of stomata. Sporophyll 3–13 cm. long, divided at summit into 14–16 fertile pinnae; sporangia ovoid, with a terminal ring: spores reniform, pitted, 76–84 μ, maturing in autumn.

On low wet banks with sphagna or in sandy swamps, in the shade of larger plants; known from numerous scattered stations in the Pine Barrens of New Jersey, in Newfoundland (De La Pylaie, Waghorne), and in Nova Scotia (E. G. Knight). The station credited to New York by Prantl from the Berlin Herbarium, is probably a mistake, though there is no reason why it should not be found on the sandy plains of Long Island and Rhode Island.

According to Prantl there are nineteen species of *Schizaea*, of which five are Polynesian, eight are found in Brazil, and five in the West Indies; all are of restricted distribution, and in most species they are known from few stations. Of *Lygodium* he records twenty-two species, of which five are Mexican and Central American, four West Indian and only one from northeastern North America, *L. palmatum*. Of the forty-six species of *Ornithopteris* and *Anemia* known, Brazil has thirty-five, Mexico nine, the West Indies six and only two extend into the United States, *O. adiantifolia* (L.) Bernh., and *O. Mexicana* (Kl.) Underw.

The Schizaeaceae are represented in the Tertiary by several

species of *Lygodium*, and by *Anemia* in the Cretaceous. Thus far *Schizaea* is unknown in the fossil state. We may safely conclude, however, that its maximum development in North America must have been reached previous to the Glacial period, and that it is in a degenerate condition and retrograding distribution in the only surviving species, *Schizaea pusilla*, whose larger and more highly developed relatives exist now only in the tropics.

SPORES

The spores of *Schizaea pusilla* measure 76–84 μ, are nearly reniform (Fig. 1), and have a cuticularized exospore which is alveolate (Figs. 2, 3); on the concave side there is a ridge extending nearly two thirds the length of the spore, formed by the exospore having a fissure nearly its whole length (Fig. 4). It is through this slit in the exospore that the young tube emerges when the spore germinates.

The development of the gametophyte from the spore to the first archegonium could not be followed in the laboratory; but from the laboratory cultures and the different stages of spore germination found in the soil brought up from New Jersey a fairly good idea of the manner and rate of growth may be drawn.

Spores, from the plants collected in July and matured in the greenhouse, were sown on September 5th; on the 14th they were found to be slightly green; the first signs of germination were seen on the 27th, when the spores contained some chlorophyl, and two had started to send out a tube which extended 27 μ beyond the aperture (Fig. 5); chlorophyl was visible in the lengthening tube on the 8th and rhizoids were also found on that date; the first cross-wall was formed on the 10th; on October 1st the second wall was formed making a filament of two cells (Figs. 9, 10).

On August 28th a spore was found in the sod of young plants which had germinated and formed a small rhizoid, slightly brown, with a curved apex and contained some chlorophyl, and a filament, 115 μ in length, of two cells (Fig. 19), the cell at base was shorter, about twice as long as broad, containing chlorophyl with no special arrangement; the other cell was nearly four times as long as broad, the chlorophyl denser at the apex and a newly formed wall (Fig. 19, *a*). The density of the chlorophyl increased at the

apex. On August 30th the chlorophyl showed a tendency to assume its final arrangement in the filament, being very dense in the center, radiating toward the walls in rather thick bands and connecting with a layer next to the wall through the whole length of the cell; on August 31st the filament had lengthened to 126 μ and one more cell had been cut off (Fig. 21), no further change in the rhizoid having taken place. The filament consisted of five cells by September 2d. On September 4th the filament had increased to six cells, and a partial division of the contents of the apical cell had taken place (Fig. 22). The tip of the filament was very much curved and densely packed with chlorophyl; the basal cell of the filament had become slightly swollen near its apical end. The filament measured 146 μ.

On September 5th the filament consisted of six cells (Fig. 23); the first walls formed were very nearly as thick as the cross-walls of the older filaments.

The older filaments generally grow erect, and this tendency toward an upward growth is plainly shown even as early as the third cell of the filament; the rhizoid also showed geotropic curvature. One tube, issuing from the fissure of an exospore, was directed downward; but soon began a curvature which was continued until the filament occupied a vertical position; the rhizoid, first directed horizontally, soon curved downward. The filaments, for the most part, did not show the tendency to upward growth until two or three cells had been formed, but the rhizoid took a downward direction much earlier.

On September 5th another spore was found in the soil consisting of one filament of six cells (Fig. 24); at the base of the filament, at its connection with the spore, there was a cell which had evidently been the basal cell of another filament. The remaining filament had given rise to two antheridia, which though not dried up were empty; one antheridium arose from a short branch from the second cell, occupying the terminal cell of the branch; the other originated from the terminal cell of the filament.

A spore with a healthy filament of four cells (Fig. 26) had borne an antheridium in which the mother cells of the antherozoids could be easily seen.

The attachment of the spore appears to be of long duration, as antheridia are formed while the filament is still attached.

A sporangium (Fig. 27) filled with spores was sown at the same time with the free spores on September 5th, and a great number of the spores germinated inside the sporangium sending out filaments through a basal break; when the spores were removed from the sporangium they were found to be more advanced than those germinating outside, the rate of growth of the spores in the sporangium in a given time being almost twice that of the other spores.

Branches were given off from the basal cells of the filaments, sometimes from apical portions of young filaments, and in a few cases the spore cell was found to divide into three primary cells (Fig. 17).

Intermediate stages between the earliest developed filament from the spore and the much-branched protonema are lacking.

PROTONEMA

The protonema occurs on the substratum, or on rootstocks of other plants, as small tufts of a dark green color, growing to a height of 2 mm. and a breadth of 4 mm.

The protonemal filaments are larger than the protonema of mosses. A comparison was made with *Pogonatum brevicaule* and *Mnium punctatum* with the following results:

	Length	Breadth
Cells of *Pogonatum brevicaule*	46 μ 76.9 μ	7 μ
Cells of *Mnium punctatum*	115 μ 96 μ	15 μ 23 μ
Cells of *Schizaea pusilla*	192 μ 173 μ 134 μ	92 μ 38 μ

It is also seen from the above that the cells of the filaments of *Schizaea pusilla* are fairly uniform in dimensions. They are densely filled with chlorophyl; starch is present. The cells are cylindrical, sometimes flattened near the base, in the region of the archegonia. Some few of the cross-walls were found to be perforated.

The protonema is copiously branched, the branches being generally single from each of the cells of the filament, generally near the upper end of the cell (Figs. 72, 73). Occasionally three or four in succession will give rise to two branches from opposite

sides, but maintain the same relative position (Fig. 30). The branches, which give rise to the spherical cells to be described below, divide in the same manner as the main filaments. The division of other branches is very irregular (Figs. 29, 30, 31). The rhizoids are not usually formed directly from the ordinary cells, but from specially modified cells (Fig. 38, *a*); in three instances only were rhizoids found directly on the filaments, and in one case one cell gave rise to two rhizoids. They arise as lateral branches, at right angles to the long axis of the filament and taking the place of branches (Figs. 38, 39). There were two cases found (Figs. 32, 33) where the cells of a branch, near the apex, had formed partition walls. In Fig. 32 the third cell from the apex had divided up into four cells, showing a tendency to form a flat prothallus. Three cells showed signs of division (Fig. 33): these two instances were the only ones found. Bower speaks of flattened expansions on the filamentous protonema of *Trichomanes alatum* and *Trichomanes sinuosum* as described by Mettenius. These are much more rudimentary in *Schizaea pusilla*.

Some cells of the filament have been found to undergo division in the later stages, into a number of disk-shaped cells which do not increase in the axial diameter. Constrictions sometimes follow such divisions at the older cross walls; the cell walls were a light brown and showed signs of decay. Fig. 35 shows the cells of the filament undergoing the same process, but these were as healthy as the rest of the filament and densely filled with chlorophyl. Bower refers (Ann. Bot. **1**: *pl. 1. f. 8*) to a similar development in *Trichomanes pyxidiferum* and says that "* * * possibly the moniliform development is merely a pathological condition; its appearance, however, is suggestive of that segmentation of the protonema into spherical cells which is recorded as a mode of vegetative propagation for the protonema of *Funaria hygrometrica*."

After some of the filaments have formed several cells the apical cell cuts off a new cell, which, after the first partition wall, that is transverse septum, divides longitudinally, forming two cells (Figs. 36, 37). These cells become large and round, each cell containing chlorophyl, and giving rise to one, or generally two, rhizoids (Fig. 37, *a*). The rhizoids also contain chlorophyl and early take on a dark yellow color. The original cell of the fila-

ment from which these cells arise either continues its growth normally (Fig. 36), or by a lateral innovation (Fig. 37). This new filament, after the formation of two or three cells, may form spherical cells at its apex (Fig. 39), or continue for some time before doing so, or it may send off a branch at once, which in its turn forms spherical cells. Generally a filament forming the spherical cells once does so at intervals throughout its whole length (Figs. 72, 73). These branches early bend to the substratum. If examined at this stage they will be found to have lost their former contents and to be filled with fungal hyphae (Fig. 43). This fungus does not injure its host, but sets up a symbiotic connection by which it functions as an absorbing organ to supply the gametophyte. So the spherical cells are undoubtedly formed by the gametophyte for the reception of the fungus, which enters as soon as the rhizoids touch the substratum (Fig. 41). While above ground and filled with chlorophyl they do not show any evidence of the presence of a fungus. The rhizoids wither early and absorption is carried on almost entirely by the fungal hyphae. The lack of rhizoids on the filament is thus explained by the presence of this fungus symbiont. The rhizoids formed from these spherical bodies appear to be the only channels through which the fungus enters the chambers built for it.

As to the nature of the fungus it is at present impossible to give it a permanent place in any of the series because of lack of evidence in regard to its method of reproduction. Perithecia have been found with asci and also what was probably a conidial stage; fruit bodies of other forms have also been found among the filaments; however, none of these were connected with the fungal hyphae under discussion. The young filament shortly after germination was in some few cases attacked by a fungus (Fig. 17, *d*), and this fungus is found wrapped around many of the cells of the older filaments, several instances having been found where haustoria had penetrated into the cells. Some of the plants are so infected by fungi after the growth of the sporophyte has begun that all the filaments have thickened walls and are pierced by three or four haustoria in each cell; they have turned brown and lost their contents. This fungus not only clings to the gametophyte of *Schizaea pusilla* but attacks the sporophyte also, though it does

not appear on the sporophyte until the first leaf has reached a height of 1 mm. It resembles the one referred to by Bower in his work on *Trichomanes*. No connection has yet been made between these hyphae and those of the fungus symbiont. As far as is known at present, the fungus which wraps itself around the protonemal filaments is the same or at least bears a very close resemblance to that which attacks the sporophyte both on the rhizome and leaf.

The hyphae of the symbiotic fungus penetrates the rhizoid generally a short distance back from the tip (Fig. 41, *c*). These hyphae sometimes branch in the rhizoid and their cross-walls are more numerous, and in many cases the hyphal threads appeared narrower. They enter the large spherical cells where they form bladders or granulated swellings in these cells, sometimes nearly filling them (Figs. 42, 43). The fungus sometimes penetrates the ordinary cells of the filament, entirely changing the shape of these cells. Pale brown bodies were found of irregular outline attached to the hyphae which were apparently sporangia.

ANTHERIDIA

The antheridia are produced laterally on the protonema, occupying the terminal cell of the lateral branch or more rarely the terminal cell of a filament, which continues its growth laterally or ends with the formation of the antheridium. They are found either singly or in groups; and may be considered as metamorphosed branches as in Fig. 44. They may either be formed from the terminal cell of a short lateral branch (Fig. 44) or from the terminal cell of a branch given off from the basal cell (Figs. 44, 48) or from the second or any other cell of a lateral branch (Fig. 44) or rarely they may be formed on the terminal cell of a short lateral branch given off from the same cell of the filament as a previous antheridial branch (Fig. 46). Occasionally these groups are borne on a branch of the filament which bears only antheridia (Fig. 48) and for the most part in groups, sometimes from both sides of a branch. These branches which bear the antheridia, whether it is a branch of two cells with the apical one becoming an antheridium, or one of the groups, occupies the same relative position on the filament as do the branches of the main filament.

One or two were found to start out from the center of a cell of a filament. The antheridia are produced in great quantities but a great number of them are aborted, and the majority of antheridia terminate a branch of two cells. They occur nearer the apex of the filaments than the archegonia, and sometimes on the same filament with the archegonia (Fig. 57). They also occur on a branch from the filament which gives rise to the archegonia; when they are borne on a separate filament they are generally formed in larger quantities. The cells of a filament which give rise to the antheridial clusters are often broader and sometimes shorter than the ordinary cells.

The antheridium is formed by a cell of a filament sending out a cell which divides by a partition wall near the apex (Figs. 49, 50). This apical cell enlarges and soon cuts off another cell by a wall parallel with the first (Fig. 51). This small cell does not elongate but always remains short and forms the pedestal for the antheridium; the apical cell becomes large and globular and cuts off a cap cell at the summit, with the wall oblique (Fig. 52); the large cell divides up into the mother cells of the antherozoids (Figs. 52, 53, 54) and one ring cell. In some cases there appear to be a single layer of two or three peripheral cells. The ring cell (or cells) contain chlorophyl though they lose this before the antherozoids are matured. Dehiscence takes place by the swelling of the ring cell and the rupture of the cap cell. The antherozoids appear to be surrounded by a very fine membrane when they escape from the antheridium (Fig. 55); they are spirally coiled, with cilia at their anterior ends. Very few ripe antheridia were found. The antherozoids do not seem to be produced in large quantities.

ARCHEGONIA

The archegonia occur nearer the base of the filaments than the antheridia (Fig. 57) on cells of the filaments which have become more than one cell wide through division. They generally bear the same relation to the original cell of the filament as do the branches from other cells; they are borne singly or in pairs (Fig. 63), sometimes in groups of three or four (Fig. 58) often on both sides of the protonema. One filament was found which gave rise on six consecutive cells to two archegonia each; two cells above

the sixth cell there was another archegonium formed, and a cell above this another one, and branches also gave rise to archegonia. There is no filament that is specially reserved for the formation of archegonia as is sometimes the case with the antheridia. Each archegonium is derived from a single superficial cell.

The archegonia are formed by the division of the initial cell into three cells ; the basal cell forms the venter which may or may not be imbedded in the cell of the filament. Some of the division cells of the original cell of the filament grow up around it in such a way as to make it appear as if imbedded (Fig. 65). From the neck cell arises the neck of the archegonium, consisting of four rows of cells, of four cells each (Figs. 60, 62, 63) ; a uniformity which produces a straight neck to the archegonium.

Occasionally the cells of the two rows on the posterior side, though they do not increase in number, become larger than those on the anterior side (Fig. 62) thus slightly bending the neck toward the anterior side. From the middle cell of the superficial mother cell arises the central cell and the canal cell ; the middle cell becomes sharply pointed on the upper end and forces itself between the neck cells ; this point is cut off, forming the canal cell ; the larger cell divides again into two cells of unequal size : the smaller and upper one forms the ventral canal cell, the lower and larger one forms the egg cell (Fig. 59). When this is mature the canal cells dissolve into mucilage. When the archegonium opens, the four stigmatic cells, which in this species are very large, are not thrown off but fold back (Fig. 63). It is at this stage that the curve in the neck occurs in some archegonia due possibly to the fact that as the filaments grow erect or nearly so, the archegonia occupy the portion of the filaments below the antheridia, and by bending the neck they bring the canal to the oösphere in a more direct line for the capture of the antherozoids, an adaptation tending to secure fertilization. Generally several archegonia are present, but only one seems to give rise to a sporophyte.

The cushion of cells on which the archegonia are borne can hardly be called an archegoniophore as some of these cells give rise to vegetative branches (Fig. 65). Three cases were found where an archegonium arose directly from a cell of the filament without any partition other than that of the formation of the ar-

chegonium. Bower (*l. c.*, Figs. 11, 12) says in his description of the archegonia of *Trichomanes pyxidiferum*, "The archegonia are borne on massive growths (archegoniophores). * * * In one case, however which has a special interest the mass of tissue on which the archegonia are produced is obviously the result of partition of a single cell of a filament, without any marked increase in size having taken place (Fig. 13). This may be regarded as the simplest form of an archegoniophore hitherto described in any fern or even in any Bryophyte and it approaches near to that suggested by Goebel as the simplest possible, in which the sexual organs would be inserted directly on the protonemal threads."

The act of fertilization was not seen, nor the direction of the first wall, but, from later stages they appear to be formed as is common with most ferns; a wall is formed parallel with the long axis of the archegonium, then a cross-wall is formed.

FOOT

The foot is in most cases extremely large, and is in every case a well-defined organ, consisting of a great mass of cells which for the most part contain chlorophyl (Figs. 69, 70, 71). It remains attached to the protonema for some time, having been found in connection with it after the formation of the third leaf (Fig. 75, *a*), and even here it appeared to be in a healthy condition as did also that part of the protonema on which the foot was borne. It grows down into the cushion of the gametophyte (some of the cushion cells appear to grow up around it). The venter cells grow and form a calyptra around the embryo covering it for some little time; remnants of it were found still clinging around the first root after the formation of three leaves (Fig. 75, *b*).

ROOT

The primary root is a prolongation of the main axis of the sporophyte (Figs. 71, 72, 73), while the ultimate roots are always adventitious and produced in acropetal succession. They arise from all sides of the erect rhizome (Fig. 79), the epidermis of which sends out rhizoids. The primary root is persistent and becomes quite long. The second and third roots have a vestigial structure which covers them as the coleorhiza of some endogens

(Fig. 76). The roots are fully formed and have root caps (Fig. 75, *d*). This root cap (Fig. 76) consists of four large pear-shaped cells, inflated on one side; the inflated side is away from the root, the concave side rests on the root tip. They are developed before the root sheath splits. The cells are replaced from the tip and, as the older ones do not always fall off when the new ones have been formed, there have been seen as many as five series (Fig. 77), though they show their age by the partial discoloration of their walls.

The epidermal cells are large and thin-walled; the outer walls often bend into the cavity of the cell and frequently break. The cortex consists of two layers; the cells of the inner layer are very large and have the walls that lie next to the endodermis thickened; but in no instance was the thickening found to be as great as that figured for *Schizaea Pennula*. There is an endodermis of two layers, and the central cylinder (Fig. 78) is like that described by Prantl (Untersuch. Morph. Gefässkrypt., *pl. 4*) for *Schizaea Pennula.*

Sclerosis takes place in all the layers without any marked increase in the thickness of the walls.

RHIZOME

The rhizome is erect (Fig. 79), occasionally creeping. It always forms a protective covering of trichomes over the growing end (Fig. 74, *d*); these trichomes consist of from two to five cells (Fig. 75, *h*), measuring 1 mm. in length which soon turn brown and are persistent. The internodes are of varying lengths. One rootstock (8 mm.) had borne nineteen sterile and two sporophylls, all dead except the five sterile leaves last formed. The fertile leaves measured 6.5 cm., the longest sterile leaf 4.5 cm. Another rhizome of the same length had twenty-two sterile leaves, six green and two nearly brown, with two fertile; these were 7 cm. high, the base of the fertile leaves was green, the sporangia brown and mature. There were twenty-two roots—six short and young; one root was 25 mm. long and had branched; the branches were 5 mm. long.

A cross-section near the young tip shows a central bundle with a well developed endodermis (Fig. 80). Sclerosis takes place in the entire cortex; the different stages are beautifully shown in

young sections; these cells, including the epidermis, are filled with starch. The epidermis and cortex are often invaded by fungal hyphae.

The vascular bundle is concentric; the xylem portion is enveloped in the phloem. The central cylinder is surrounded by a well-defined endodermis and phloem sheath, the radial walls of which are thin and fragile; the phloem elements are represented by two or three imperfect rows of narrow parenchymatous cells and sieve tubes; the xylem consists of scalariform tracheids with occasionally small spiral tracheids close to the phloem. The medullary parenchyma is composed of large, thick-walled cells, pitted, and early showing sclerosis, but not as early as the fundamental tissue outside the bundle.

STERILE LEAVES

The sterile leaves are linear, slender and tortuous. The development of the leaf is very slow, the lower portions having long been fully formed while the apex is still unfolding. The vernation is circinate (Fig. 79). Owing to the more rapid growth of the cells on the dorsal side than those on the ventral, the leaf is rolled up on the ventral side. When fully developed they bear on their dorsal side two rows of stomata alternating with three rows of glands (Fig. 81), sometimes four or more rows of glands. The glands seem to originate from special cells cut off from the epidermis; these epidermal cells frequently do not lengthen, keeping very nearly an isodiametric shape; when they do lengthen the glands remain at or near the upper wall.

The young leaves and the tip of the stem are more or less completely clothed with trichomes early turning brown. These are not to be confounded with the glandular hairs. They are composed of two or more cells and are extremely long, measuring in some instances 1 mm. to 3 mm. or perhaps more. The longest glands of the leaf measured nearly 100 μ, others 76 μ and in width 31 μ. Some are composed of one cell, others of two cells; they are all club-shaped and contain granular protoplasm. These glands were rarely found on the ventral surface, and sometimes they did not appear to follow any law as to their formation on the dorsal surface, though, for the most part, they were formed in alternate rows with the stomata.

The stomata are restricted to two rows of epidermal cells and almost every epidermal cell in these rows gives rise to one (Fig. 82). A cell of the epidermis before it has lengthened forms a U-shaped wall at the upper end of the cell (Figs. 86, *a*, *b*); the points of the U meet the radial wall which separates this cell from the one next above (Fig. 86, *b*); this cell becomes the mother cell of the stoma, and by growth presses the partition wall back a short distance into the upper epidermal cell (Fig. 86, *e*). This cell divides by a tangential wall into two cells of equal size; these become the guard cells (Fig. 86, *c*, *d*) each containing abundant chlorophyl. These guard cells enlarge considerably (Fig. 86, *d*, *e*) so that they are raised above the epidermis as shown in an oblique view (Fig. 83). The wall between the guard cells splits along its central portion making an opening to the space below; the epidermal cell meanwhile has lengthened and the cell above has formed a stoma in the same way. The leaf bundle is more nearly collateral than that of the stem; the xylem faces the ventral, the phloem the dorsal surface of the leaf (Figs. 88, 90). There is a two-rowed endodermis around the bundle; the epidermal cells are large and in some instances occupy one half of the cross section. The ground tissue is made up of thin-walled parenchyma with numerous air spaces (Fig. 89) and the cells contain chlorophyl.

SPOROPHYLL

The sporophyll is very similar to the sterile leaf with the exception of the formation at its apex of pinnae bearing the sporangia; these have been carefully studied by Prantl and others in several species of *Schizaea*, the descriptions of which, from present observations, appear to hold good for *Schizaea pusilla*. One of the largest sporophylls measured 13 cm. from base to apex, the portion bearing the pinnae was 6 mm. long and eight pinnae were formed on one side and seven on the other; the longest pinna measured 4 mm., of this 2⅔ mm. is the portion which bore the sporangia. The lowest pinna on each side had formed four sporangia each, the others eight each. Prantl figures six sporangia for *Schizaea dichotoma*, and sixteen for *Schizaea Pennula*. The edge of each pinna rolls up over the sporangia, forming an indusium, and the end cells at the summit and also along the mar-

gin produce trichomes which also cover the sporangia. These trichomes are often composed of more than one cell, and resemble the trichomes formed by the rhizome and are in some instances as long as 134 μ, 345 μ, 461 μ, the width being 38 μ, and 30 μ.

A surface view of the dorsal side of the sporophyll shows two rows of stomata alternating in some cases with rows of glands, though these sometimes are not in rows, and occasionally only two glands were found. These glands are smaller than those generally found on the sterile leaf measuring only 38 μ.

The stomata appear sunk below the epidermis, but a cross-section showed them to be the same as in the sterile leaf. The two rows of stomata continue up the leaf from the base to the pinnae, where they are lost in a great number of stomata which cover the dorsal surface of the pinnae with no special arrangement. No glands were found on any of the pinnae examined.

The warts or swellings from the epidermal cells are far more numerous in the sporophyll, though they are found on the sterile leaf (Fig. 93, *a*). They do not appear to follow any law as to their arrangement on either leaf, though they appeared to be more numerous on the ventral side. The epidermal walls are thicker than the epidermal walls of the sterile leaf, some of which had extremely thin walls and a rudimentary bundle (Fig. 90).

The bundle has a well-marked endodermis ; it appeared from the cross-section to be collateral as did all the bundles with the exception of that of the rhizome (Fig. 94). The elements of the bundle were not traced out, but reticulated and ring tracheids were found in the xylem. The mesophyll tissue of the sporophyll (Fig. 89) is composed of thin-walled cells with numerous air spaces : these cells seem to be branched in a stellate manner in both sterile leaves and sporophylls.

SUMMARY

The spores are small, are nearly reniform, and have a cuticularized exospore which is alveolate. There is a ridge along the concave side having a fissure nearly its whole length through which the young tube emerges when the spore germinates. Out of a great number sown at one time only two had germinated by the end of the third week, the others taking a longer

time. The spore remains attached for some time after the formation of antheridia.

The gametophyte is a filamentous protonema, irregularly branched, bearing both antheridia and archegonia on the same filaments ; and producing rhizoids from specially modified cells which are inhabited by a symbiotic fungus.

The antheridia occur singly, or in groups on special branches bearing antheridia alone. They are produced in great numbers though but few ripen. They are simple in their structure and the first wall formed in the antheridium is parallel with the wall cutting it off from the lateral branch, forming a pedicel. A small number of antherozoids are produced in an antheridium, which are enclosed in a membrane when they escape from the antheridium.

The archegonia arise at, or near, the base of the filaments, either directly on the filament or, morè often, on cushions formed by the division of the cell of the filament. They are characterized by the uniformity of the neck rows and the large size of the stigmatic cells.

The foot is a large, well-defined organ, remaining attached to the protonema for some time after the formation of the third frond, carrying nourishment from the gametophyte to the embryo which is far advanced before it breaks through the calyptra.

The primary root is persistent. The second and third roots have a vestigial sheath through which they do not break until after the development of the root-cap. The root-cap consists of four large pear-shaped cells inflated on the side away from the root tip.

The rhizome is erect, always forming a protective covering over the growing end ; the trichomes are large, turn brown early, and are persistent.

There is a central concentric bundle with a well-marked endodermis. Sclerosis takes place in the entire cortex, the cells of which, with the epidermis, are filled with starch. The epidermis and cortex are often invaded by a fungus hypha.

The sterile and fertile leaves have two rows of large stomata, on the dorsal side, alternating with two or more rows of glands ; these glands are small and sometimes wanting on the fertile leaf. The young leaves are more or less completely clothed with

trichomes. Warts or swellings occur from the epidermal cells on both surfaces, though more numerous on the ventral side.

The bundles appear collateral with a well-marked endodermis. The mesophyll tissue is composed of thin-walled cells, branched in a stellate manner.

Explanation of Plates

Plates 1, 2, 3 and 4 were drawn from a magnification three times as great as expressed in the numbers which represent the magnification of the figures as they stand in the reproduction.

PLATE 1

1. Different views of the spore, × 80.

2. Spore, × 140.

3. Portion of exospore, × 333⅓.

4. Ridge and fissure in exospore seen from above, × 195.

5–17. Different stages in the germination of the spore, × 58⅓. *a*, filament; *b*, rhizoid; *c*, *c*, new branch.

18. Germinating spore of *Botrychium obliquum*, two weeks and five days, × 58⅓. Sown at same time as *Schizaea* spores. The last-named did not start to germinate until after three weeks.

19. Germinating spore found in soil on August 28, × 80. *a*, Indication of cross-wall.

20. The same on August 29. *a*, cross-wall formed.

21. The same on August 31, × 30.

22. On September 4, × 30.

23. On September 5, × 30.

24. Spore found in soil on September 5, × 30. *a*, antheridia; *b*, swelling at base of terminal antheridium.

25. The same with wall formed at *a*.

26. Filament of four cells with antheridium showing mother-cells of antherozoids (*a*). *b*, Rhizoid, × 80.

27. Sporangium with spores germinating inside, × 30. Owing to position in which the sporangium fell when sown—the filaments from the spores are not sent out though the regular fissure at *a*.

PLATE 2

28, 29, 30 and 31. Methods of branching of the protonemal filaments.

32 and 33. Cells of the filament dividing.

34 and 35. Cells of the filament becoming moniliform.

36. Young spherical cells with the longitudinal wall (*a*) just forming, × 80.

37. Older stage of the same showing young rhizoids (*a*, *a*) and young branch starting from filament at base of spherical cells *b*, × 80.

38. Portion of filament showing spherical cells, antheridia, and archegonia. *a*, spherical cells; *b*, rhizoids; *c*, fungus in spherical cells; *d*, antheridia; *e*, archegonium, × 30.

39. Shows position of spherical cells, × 30.

40. Abnormal condition. One cell of the filament giving rise to one spherical cell, and a cell of the filament next above giving rise to two, × 30.

41. End of rhizoid showing fungus penetrating into the cell. Shaded portions are hyphae which are inside the rhizoid, × 195.

42. Upper part of same showing portion of spherical cell with the bladder-like hyphae (*b*). A hypha in rhizoid, × 195.

43. Spherical cells filled with fungus *a*, × 140.

PLATE 3

44, 45, 46 and 47. Different ways of branching of antheridial filament.

48. One of the antheridial branches with antheridia in different stages of completion. *a* shows one filament giving rise to three, × 30.

49, 50, 51, 52, 53, 54, 55 and 56. Stages in formation of the antheridium. Fig. 49, × 80, first cell sent out from main filament. Fig. 50, × 30, later stage showing first wall cut off near tip. Fig. 51, × 80, older stage. Terminal cell *a* becomes the antheridium ; cell *b* the pedestal. Fig. 52, × 140, *a*, cap cell ; *b*, mother cells of the antherozoids. Fig. 53, × 140, later stage. Fig. 54, × 140, ripe antheridium before splitting cap-cell. Fig. 55, × 333⅓, antherozoids still in membrane. Fig. 56, empty antheridium.

57. Branch showing antheridia and archegonia. All the antheridia but *a* are aborted, × 16⅔.

58. Young archegonia, × 140.

59. Young archegonium, × 30. *a*, canal cell ; *b*, ventral canal cell ; *c*, egg cell.

60. Older stage of same before opening, × 80.

61. Looking down on the four stigmatic cells of the archegonium, × 80.

62. Archegonium opening, × 80.

63. Showing large stigmatic cells (*a*) folding back, × 80.

64. Cell of the filament dividing up before the formation of the archegonia, × 140.

65. The same with an archegonium, × 30.

PLATE 4

66 and 67. Upper and under view of egg cell after fertilization enclosed in the calyptra, × 30.

68. Young embryo, × 30.

69. *a*, gametophyte wlth archegonium. *b*, foot ; *c*, leaf ; *d*, stem of sporophyte, × 30.

70. Young sporophyte. *a*, foot ; *b*, leaf ; *c*, stem ; *d*, trichomes ; *e*, gland on rond ; *f*, calyptra, × 80.

71. Young sporophyte. *a*, foot ; *b*, root ; *c*, frond ; *d*, calyptra.

72 and 73. Two stages in the growth of the sporophyte showing curled tip of frond. Marking the same in both. *a*, gametophyte ; *b*, sporophyte ; *c*, calyptra, × 12⅓.

74. *a*, Rhizome ; *b*, root ; *c*, first leaf ; *d*, trichomes.

Plates 5, and 6 were drawn from a magnification twice that expressed in the numbers which represent the magnification of the figures as they stand in the reproduction.

PLATE 5

75. Sporophyte still attached to gametophyte after the formation of the third leaf. *a*, foot ; *b*, portion of calyptra ; *c*, root ; *d*, young root, the dotted lines indicate root-cap which can be seen through the vestigeral covering ; *f*, leaf ; *g*, rhizome ; *h*, trichomes which cover tip of young leaf and rhizome ; some have been removed to show glands on leaf ; *i*, gametophyte, × 45.

76. Young root just emerging from its covering, × 87½.

77. Root-cap; here shown in five series.

78. Cross-section of root. *a*, thickened inner walls of cells of the ground tissue next to endodermis (*b*); *c*, phloem; *d*, xylem, × 292½.

79. Showing rhizome with four leaves and five roots; *a*, rhizome; *b*, roots; *c*, trichomes (the internode here represented is unusually long and distinct), × 8.

80. Cross-section of rhizome not far from tip, × 120. *a*, cells filled with starch; *b*, endodermis; *c*, phloem; *d*, xylem; *e*, fungus hyphae entering epidermal cells.

PLATE 6

81. Surface view of dorsal side of sterile leaf, showing the two rows of stomata with the glands alternating with them, × 120.

82. Portion of epidermis of sterile leaf with three stomata, *a*, *b*, *c*. *a*, shows the chlorophyl grains; in *b* the contents have been removed to show the original cross-wall (*d*) between the epidermal cells, and the way the guard cells (*e*) rest on epidermis at *c*, × 210.

83. Oblique view of sterile frond showing raised stomata (*a*).

84. Longitudinal section of same. *a*, epidermal cells; *b*, one guard cell of stoma; *c*, air cavity.

85. Cross-section of same. *a*, guard cells; *b*, air cavity, × 210.

86. Five diagrams showing development of stoma. 1 *b*, cross-wall between epidermal cells; 2 *b*, mother cell of stoma with U-shaped wall; *c*, formation of longitudinal wall through mother cell dividing it into the two guard cells; *d*, shows curve in original cross-wall, and the splitting of the longitudinal wall. The dotted line indicates the relative size of the guard cells which have started to swell. In *c*, the stoma is complete; 1 *c*, original cross-wall; 2 *c*, guard cells.

87. Diagram of cross-section of sterile leaf showing the two rows of stomata (*c*). *a*, bundle; *b*, endodermis, × 45.

88. Bundle from sterile leaf. *a*, endodermis; *c*, phloem; *d*, xylem, × 210.

89. Mesophyll tissue from sterile leaf, × 210.

90. Cross-section of a young sterile leaf with a rudimentary bundle, marking as in Fig. 88, × 210.

91. Diagram of cross-section of fertile leaf, marking as in Fig. 87, × 45.

92. Stoma seen in cross-section of sporophyll, × 210. *a*, stoma; *b*, air space.

93. Two epidermal cells from cross-section of sporophyll showing warts (*a*), × 210.

94. Cross-section of bundle in sporophyll, marking as in Figs. 88, 90, × 210.